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Biomechanical and neuromuscular adaptations during the landing phase of a stepping-down task in patients with early or established knee osteoarthritis

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A B S T R A C T

Background: To compare the knee joint kinematics, kinetics and EMG activity patterns during a stepping-down task in patients with knee osteoarthritis (OA) with control subjects.
Methods: 33 women with knee OA (early OA, $n = 14$; established OA $n = 19$) and 14 female control subjects performed a stepping-down task from a 20 cm step. Knee joint kinematics, kinetics and EMG activity were recorded on the stepping-down leg during the loading phase.
Results: During the stepping-down task patients with established knee OA showed greater normalized medial hamstrings activity ($p = 0.034$) and greater vastus lateralis-medial hamstrings co-contraction ($p = 0.012$) than controls. Greater vastus medialis-medial hamstrings co-contraction was found in patients with established OA compared to control subjects ($p = 0.040$) and to patients with early OA ($p = 0.023$). Self-reported knee instability was reported in 7% and 32% of the patients with early and established OA, respectively.
Conclusions: The greater EMG co-activity found in established OA might suggest a less efficient use of knee muscles or an attempt to compensate for greater knee laxity usually present in patients with established OA. In the early stage of the disease, the biomechanical and neuromuscular control of stepping-down is not altered compared to healthy controls.

1. Introduction

Osteoarthritis (OA) is a highly prevalent joint disease [1], which has been counted globally as the sixth leading cause of moderate-to-severe disability and the eight cause of burden disease in the European region [2]. Patients with OA commonly experience pain, stiffness, reduction in the range of motion and muscle weakness, factors associated with activity limitations such as the difficulty to stand up from a chair, walk or climb stairs [3,4]. Studies carried out in patients with OA have documented the use of compensatory strategies during gait such as decreased walking speed [5], decreased cadence [6], decreased stride length [7], decreased knee flexion angle during the loading response phase [8], increased step width [9], increased hip internal rotation and increased lateral trunk lean [9]. Modifications in knee loading distribution such as increases in knee adduction moment (KAM) and knee adduction angular impulse have also been reported [10,11]. A direct association between higher KAM and severity of knee AO has been found [10,11].

Changes in electromyography (EMG) activity patterns during gait including increased activity of hamstrings and increased co-contraction have been documented [12]. This increased co-activation might be an adaptation of the individual with OA to deal with pain and instability generated by the loss of joint integrity. In this view, this co-activation could increase the stiffness of the joint promoting knee stability [9]. On the other hand, those gait modifications and increased co-activation could interfere with the distribution of the load on the knee joint, leading to further joint damage and disease progression [8].

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The kinematic and kinetic characteristics during gait and stair climbing have been extensively studied in patients with knee OA in comparison with healthy subjects [8,13,14]. However, analysis of the biomechanical characteristics involved in other activities of daily living like stepping-down from a sidewalk still need to be further analysed, as stepping-down is a task that elicits complaints of instability and pain [15–17]. In addition some studies have differentiated between the characteristics of patients in different stages of the disease (early vs. established OA) but they often did not use MRI to define their groups. Knowledge of the stage in the process in which modifications in movement patterns occur might be helpful in the understanding of disease development and/or progression. It is possible that patients at risk or with early OA, defined as joint pain with structural damage detected on MRI but hardly visible on X-rays [18], respond better to certain interventions than patients with established OA.

Patients with knee OA often complain of knee instability, defined as the sensation of buckling, shifting or giving way, which usually translates into activity limitations [19]. Previous studies have estimated that between 12% and 65% of this group of patients have reported at least one episode of knee instability during the past three months [20,21].

Knee joint stabilization is thought to be influenced by active muscle force contraction and passive ligaments restraints, both of which are usually affected in patients with knee OA [20,22,23]. Evidence has shown an association between self-reported knee instability and isokinetic average knee muscle weakness [21], but not with passive knee laxity in this group of patients [24]. However, failure to control the knee usually occurs during dynamic activities [19]. Therefore, in an attempt to further explore knee stability in patients with OA, recent studies have aimed to identify the objective biomechanical and/or neuromuscular performance characteristics associated with knee instability. Those studies have reported an association between greater knee adduction moment and medial knee laxity during gait [10], and lower medial knee muscle co-contraction prior to platform perturbations in patients with medial compartment knee OA [25]. Nevertheless, to the best of our knowledge the biomechanical and neuromuscular components associated with the sensation of knee instability in those patients have not been fully recognized. In addition, further study of knee instability in patients with early OA might help to clarify the association between knee instability and disease severity. In knee OA, disease progression leads to a structural deterioration which subsequently can cause joint instability, as often mentioned in OA. Nevertheless, joint instability can also contribute to further disease progression [26].

During stair descent loading forces across the knee joints are higher than during stair ascent and level walking, making it a more challenging task requiring good neuromuscular control to obtain good shock absorption and knee stability [27,28]. Particularly the early stance phase is important during which the ground reaction forces need to be attenuated (by eccentric muscle activity) as weight is loaded onto one limb [27]. Therefore, the stance phase of a step-down task was assessed in the present study to represent the stance phase of stair descent. The stepping-down task has been used successfully to study movement strategies in elderly subjects [29] and dynamic knee instability in a patient with anterior cruciate ligament deficiency [16,30]. Therefore, the purpose of this study was to investigate the joint kinematics, kinetics and EMG activity patterns in patients with early or established OA of the knee during a stepping-down task.

We hypothesise that the analysis of knee kinematics, kinetic and EMG activity during the performance of the stepping-down task might elucidate relevant biomechanical characteristics associated with compensatory strategies for instability or pain used by patients with knee OA (early and established). Secondarily, this task might help to explore biomechanical and neuromuscular strategies associated with self-reported knee instability in this group of patients. The results might contribute to the design of intervention strategies directed to treat difficulties of mobility and knee instability in patients with knee OA.

2. Methods

2.1. Subjects

A convenience sample of 47 females was included in this study (Table 1). Patients with OA ($n = 33$) were recruited by a rheumatologist or orthopaedic surgeon from the University Hospitals Leuven. Fourteen patients were classified as early OA based on a combination of pain, Kellgren/Lawrance (KL) score = 0 or 1 on radiography and presence of at least two of four MRI criteria: (1) ≥BLOCKS grade 2 for size cartilage loss, (2) ≥BLOCKS for percentage full-thickness cartilage loss, (3) signs of meniscal degeneration, and (4) ≥BLOCKS for size of BMLs in any compartment [18]. Nineteen patients were classified as unilateral or bilateral established knee OA based on the criteria from the American College of Rheumatology (ACR) [31] and KL ≥ 2 ± [32,33]. Control subjects ($n = 14$) with no history of knee symptoms or characteristics associated with knee OA and KL = 0 were recruited from cultural or social organizations. Demographic, clinical, radiographic, neuromuscular and biomechanical factors related to OA were assessed. Total knee replacement, rheumatoid arthritis or any other form of inflammatory arthritis (i.e. crystal arthropathy, septic arthritis, spondylarthropathy) were considered exclusion criteria. All the participants provided written inform consent before testing. The study was approved by the local Ethics Committee.

2.2. Measures

2.2.1. Loading phase of stepping-down task

The subjects were instructed to step down from a wooden step (20 cm) (Figure 1) onto a force plate with the evaluated limb and to step forward with the other limb. Subjects ended in quiet stance on both legs in front of the force plate (Figure 2). The arms were kept flexed across the chest to avoid obstruction of the visibility of the reflective markers. All patients wore standard sport shoes (kelme indoor copa). A task cycle was considered from the first contact with the force plate (touch-down) until the toe-off from the force plate with the evaluated limb. In a single session, three trials per patient were recorded. Both limbs were assessed but only the index leg (see statistical analysis) was included in the analysis.

2.2.2. Knee instability

Self-reported knee instability was evaluated based on a questionnaire from Felson et al. [19,20] in which a sensation of knee buckling, shifting or giving away during the past three months was inquired. Persons reporting knee instability were additionally asked for the number of episodes of instability, on which leg it was experienced. Knee instability was dichotomized as "0" if they did not report episodes and "1" if they reported episodes of instability during the past three months [18]. An additional question about history of knee injury ("Did you ever have a knee injury?" yes/no) was formulated to persons who reported to have had at least one episode of knee instability, this with the intention to explore whether the sensation of instability could be due to another cause such as traumatic injury.

2.2.3. Muscle strength

Knee muscle strength was assessed using the Biodex System 3 Pro (Biodex Medical System, Shirley, NY, USA). An initial practise attempt was used for the participants to become familiar with the movements required. The patients performed three maximal test repetitions to measure the isokinetic strength of the knee extensor muscles (mainly quadriceps) and knee flexor muscles (mainly hamstrings) for each knee, at 60°/s." [34]. Isometric knee extension and flexion were measured in 60° flexion position. The peaks of three trials were averaged in each leg separately for isometric and isokinetic assessments (quadriceps and hamstrings torques (Nm)) and divided by patient's weight

Table 1
Characteristics of study group.

	Control subjects (n = 14)	Early knee OA (n = 14)	Established knee OA (n = 19)	p-Value	Post hoc p-value		
					Established vs control	Early vs control	Established vs early
Basic characteristics							
Age, in years	68.0 ± 3.9	70.4 ± 4.6	68.37 ± 6.7	0.457			
Height, m	1.63 ± 0.1	1.63 ± 0.1	1.59 ± 0.1	0.080			
Weight, kg	69.9 ± 9.3	73.6 ± 10.3	72.1 ± 10.4	0.621			
Body mass index, kg/m^2	26.2 ± 2.9	27.8 ± 4.7	28.5 ± 4.6	0.290			
K/L score, n (%)							
0	14(100)	–	–				
1	–	14(100)	–				
≥2±	–	–	19(100)				
Clinical characteristics							
VAS knee pain (0–10)	0.86 ± 1.3	1.64 ± 2.2	2.95 ± 2.7	0.033*	0.029*	0.624	0.233
KOOS pain score (0–100)	91.24 ± 8.4	82.71 ± 15.7	80.36 ± 14.8	0.078			
KOOS symptoms score (0–100)	89.50 ± 10.1	78.77 ± 15.4	74.96 ± 18.2	0.033*	0.028*	0.163	0.764
Self-reported knee instability, n (%)	0(0)	1(7)	6(32)	**0.026***	**0.020***	**0.309**	**0.090**
Knee static alignment							
Varus (−) or valgus (+), degrees	1.06 ± 2.1	−0.56 ± 2.5	−0.61 ± 3.6	0.216			
Neutral (>−3 and <3 degrees), n (%)	11(79)	12(86)	8(42)	**0.027***	**0.051**	**0.622**	**0.017***
Varus ≤−3 degrees, n (%)	2(14)	1(7)	5(26)	**0.164**			
Valgus ≥3 degrees, n (%)	1(7)	1(7)	5(26)	**0.337**			
Missing, n (%)	0(0)	0(0)	1(6)				
Muscle strength							
Isokinetic 60°/s							
Average knee muscle strength (Nm/kg)[a]	1.00 ± 0.2	0.88 ± 0.2	0.91 ± 0.2	0.242			
Extensor muscle strength (Nm/kg)	1.20 ± 0.3	1.01 ± 0.2	1.08 ± 0.3	0.227			
Flexor muscle strength (Nm/kg)	0.81 ± 0.2	0.76 ± 0.2	0.68 ± 0.2	0.085			
Isometric 60°							
Average knee muscle strength (Nm/kg)[a]	1.10 ± 0.2	0.99 ± 0.2	0.95 ± 0.1	0.078			
Extensor muscle strength (Nm/kg)	1.43 ± 0.4	1.28 ± 0.2	1.30 ± 0.3	0.362			
Flexor muscle strength (Nm/kg)	0.76 ± 0.1	0.68 ± 0.2	0.62 ± 0.1	0.015*	0.011*	0.217	0.445
Activity limitations							
KOOS ADL score (0–100)	94.21 ± 6.5	83.56 ± 13.2	83.78 ± 14.7	0.037*	0.058	0.066	0.999
Stair climbing test, seconds	5.67 ± 1.1	5.50 ± 1.1	5.94 ± 1.0	0.510			
Get up and go test, seconds	6.53 ± 1.7	6.28 ± 1.4	7.09 ± 1.6	0.338			
Cycle time stepping-down task[b], seconds	1.07 ± 0.2	1.09 ± 0.2	1.04 ± 0.2	0.734			

Mean ± standard deviation (SD), unless other stated. OA = osteoarthritis; K/L = Kellgren/Lawrence; VAS = visual analogue scale; KOOS = Knee Injury and Osteoarthritis Outcome Score. Bold χ^2.
[a] Average knee extensor and flexor muscle strength.
[b] Time from touch-down to toe-off.
* $p \leq 0.05$ significant difference between groups.

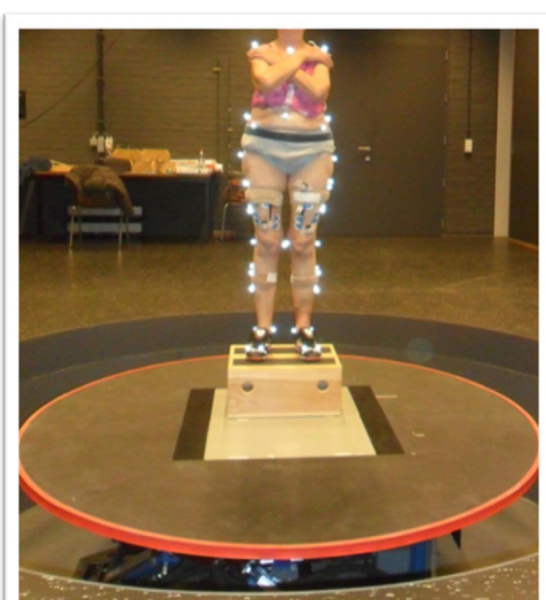

Figure 1. Subject in the initial position.

(kg). This measure (in Nm/kg) has excellent intra-rater reliability (ICC 0.93) in knee OA patients [35,36].

2.2.4. Knee joint alignment

Knee alignment was measured from anterior–posterior weight bearing radiograph of the lower limbs (Oldelft, Triahlon, Afga ADC M Compact Plus) by a single experienced rheumatologist (FL). The alignment of the mechanical axis was reported as varus if ≤−3° or valgus if ≥3°. Knee alignment between −3° and three degrees was classified as neutral [37,38].

2.2.5. Activity limitation

Activity limitations were assessed subjectively using the Dutch version of the Knee Injury and Osteoarthritis Outcome Score (KOOS) [39] which ranges from 0 (poor outcome) to 100 (good outcome), and objectively using the stair test and the get up and go test (GUG). In the stair test [35], subjects were instructed to climb five stair steps (15 cm high), turn around and descend the stairs. Participants were encouraged not to use the handrail, but were not prohibited from doing so for safety. In the GUG test [35], subjects were sitting on a high standard chair (49 cm), they were told to stand up without help of the arms on the command "go", and walk three metres through an unobstructed corridor as fast as possible, without running. Once they reached a mark on the floor, the subjects turned around, returned to the chair and sat down. Patients who normally used walking devices were allowed to use them during the test. All subjects were wearing standard sport

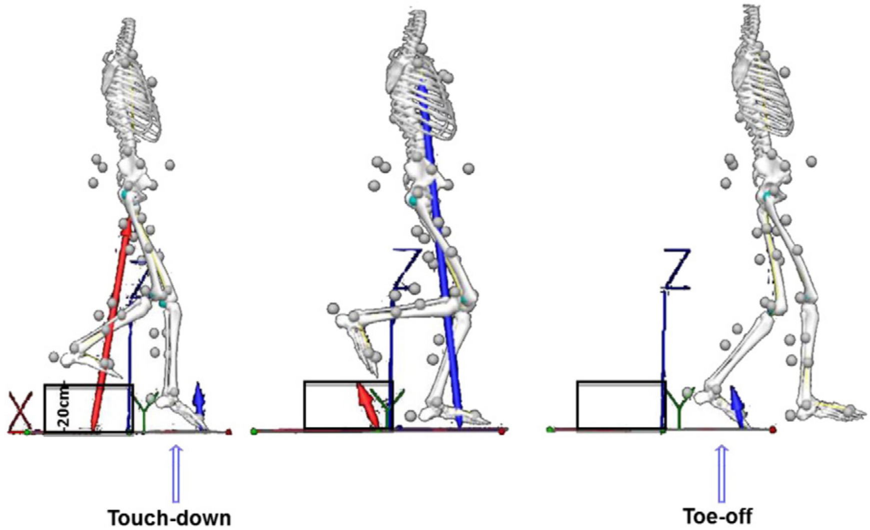

Figure 2. Stepping-down task.

shoes during the performance of the tests. The time in seconds was recorded for both tests; longer time was considered a higher activity limitation. For each test, the mean value of three trials was calculated. Both tests have shown good reliability and validity [35].

2.2.6. Pain and symptoms

Pain was assessed with the visual analogue scale (VAS), the patient was asked to range the sensation of pain during the last week from 0 (none) to 10 (severe pain). The Dutch version of the KOOS questionnaire was also used to assess pain and general symptoms, ranging them from 0 (poor outcome) to 100 (good outcome) [39].

2.3. Data capture

The stepping-down task was tracked using 6 MX-T20 optoelectronic cameras (Vicon, Oxford Metrics, UK) collected at 100 Hz in Nexus (Vicon). Eight body segments (trunk, pelvis, upper-lower legs and feet) were identified by 46 spherical reflective markers of 14 mm diameter (see Supplemental Digital Content from Malfait et al. [40] available at http://links.lww.com/MSS/A369). Segmental coordinate systems were identified as reported previously [41,42]. Simultaneously (time synchronized), data from the force plate (AMTI Watertown, MA, USA) and the EMG were sampled at 1500 Hz [34].

EMG activity of the vastus medialis (VM), vastus lateralis (VL), medial hamstrings (MH) and lateral hamstrings (LH) was recorded bilaterally using a 16-channel system wireless surface EMG system (Aurion, Italy) and silver–silver chloride, pre-gelled bipolar surface EMG electrodes (Ambu Blue Sensor, Ballerup, Danmark). The electrodes were placed over the muscle belly two centimetres centre to centre in line with the muscle fibres, and with an inter-electrode distance of three centimetres to reduce the possibility of cross-talk between neighbouring muscles [43]. Isolated manual muscle test [44] was used to validate the placement of the electrodes and to assess for cross talk [45]. Skin surface was previously shaved and cleaned with 70% isopropyl alcohol to reduce impedance.

2.4. Data processing and analysis

Separate trials were used for anatomical calibration and for calculation of hip and knee joint centres and functional axis of the model [41, 46,47]. Marker trajectories and force plate data were both filtered using a 4th order low pass Butterworth filter with a cut off frequency of 20 Hz, based on previous studies [40,48]. Touch-down and toe-off events were defined based on the vertical force crossing a 20 N threshold. Joint knee flexion angles were calculated at touch-down and at the point of peak knee flexion during the task (peak knee flexion angle (PKFA)) (Figure 3). Knee adduction moment, defined as the external load applied at the joint moving the tibia to varus position was calculated using inverse dynamics and normalized to body mass (Nm/kg). There were no clearly defined early and late peak adduction moments during the performance of the stepping-down task. Therefore, the peak knee adduction moment (PKAM) as well as the integral of the knee adduction angular impulse (KAAI) over the complete stance phase (Nms/kg) were included in the analyses. The average of three stepping-down trials was calculated for all biomechanical parameters for each participant [49]. All modelling and analyses were undertaken in Visual 3D (v.4.83, C-motion, Germantown, MD, USA) using geometric volumes to represent segments based on cadaver segmental data as described in previous studies [40,50].

EMG signals were high pass filtered at a cut-off frequency of 10 Hz [51]. The rectified EMG signals were also filtered with a 4th order zero-lag low pass Butterworth filter at a cut-off frequency of 50 Hz and subsequently normalized to the peak EMG activity of each muscle during the stepping-down task cycle [52,53]. The root mean square (RMS) from touch-down to the PKFA was calculated for each muscle on the stepping-down leg.

Muscle co-contraction index (CCI) for the medial (VMMH = vastus medialis-medial hamstrings) and lateral (VLLH = vastus lateralis-lateral hamstrings) sides of the knee joint, as well as for the oblique surface of the knee joint (VLMH = vastus lateralis-medial hamstrings), were calculated from touch-down to the PKFA according to the following equation [54]:

$$CCI = EMGS/EMGL \times (EMGS + EMGL)$$

in which EMGS is the normalized magnitude of the EMG signal for the less active muscle and EMGL is the normalized magnitude of the EMG signal for the most active muscle. To determine whether medial to lateral co-contraction was imbalanced muscle co-contraction medial to lateral ratio was calculated dividing medial co-contraction index with lateral co-contraction index [55].

The co-contraction index used here represents the balance of EMG activity between pairs of antagonistic muscles and it is commonly used in the literature [55]. However, it is important to consider that EMG signal does not reflect muscle force and hence this index does not provide direct information about the magnitude of knee loading.

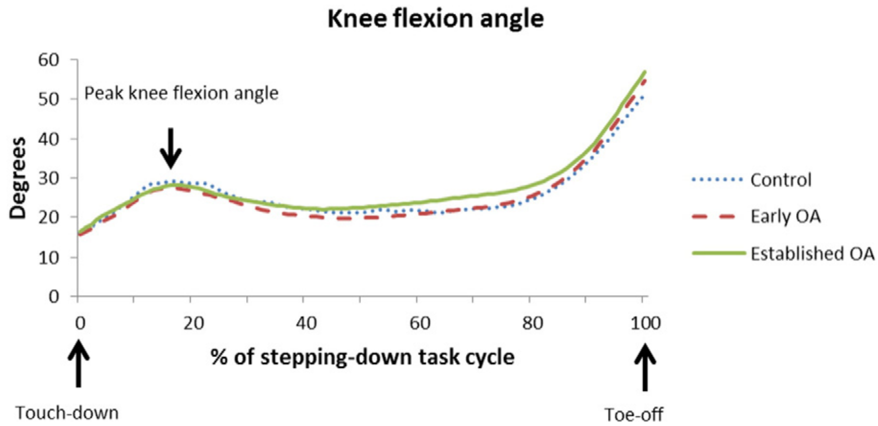

Figure 3. Lines represent the mean knee flexion angle per group.

2.5. Statistical analysis

For the patients with knee OA an index knee was selected using the following decision tree: 1) knee with established or early OA (ACR and KL score), if OA diagnosis was the same in both knees, 2) instable knee and 3) painful knee. In participants in whom an index knee could not be defined based on these signs, a random index joint was assigned. For the control subjects the right knee was used as reference. The variables related to the index knee were used in the analyses.

Descriptive statistics were used to characterize the study population, as well as the patients with knee OA and control subjects separately. Percentages were used for categorical variables, and means and SDs for continuous variables. One-way analyses of variance (ANOVA) and chi-square tests were used to analyse the differences in the distribution of the variables between the three subgroups.

ANOVA-Tukey post hoc tests were used to test the group difference in knee joint angles, external moments and EMG activity between subjects with established OA, early OA and control subjects. Chi square tests (χ^2) were used to compare self-reported knee instability between the study groups. Independent t-tests were used to compare the patients' characteristics, joint kinematics, kinetics and EMG activity patterns during a stepping-down task in patients with and without self-reported knee instability. Statistical significance was accepted at p-values ≤ 0.05. All analyses were performed using SPSS software, version 17.0 (SPSS, Chicago, IL).

3. Results

3.1. Descriptives

The mean age of the females that participated in the study was 68.9 (±5.4) years old. Patient with established knee OA had significantly more knee pain ($p = 0.029$) and lower isometric knee flexor muscle strength than the control group ($p = 0.011$). A lower percentage of patients with established OA had their knees in neutral alignment compared with patients with early OA ($p = 0.017$), the difference was borderline significant when comparing with control subjects ($p = 0.051$). No significant group differences were found in other variables assessed including activity limitations. Further, demographic, clinical and neuromuscular characteristics are shown in the Table 1

3.1.1. Knee biomechanics and EMG activity patterns during the loading phase of stepping-down task

There were no significant differences in kinematics or kinetics between the groups with knee OA (early-established) and/or the control group during the loading phase of the stepping-down task. Patients with established knee OA showed greater normalized medial hamstrings activity ($p = 0.034$) and greater vastus lateralis-medial hamstrings co-contraction ($p = 0.012$) compared with the control subjects. Higher vastus medialis-medial hamstrings co-contraction was found in patients with established OA compared

Table 2
Kinematics, kinetics and muscle activity during the stepping-down task.

	Control	Early OA	Established OA	p-Value	Post hoc p-value		
	($n = 14$)	($n = 14$)	($n = 19$)		Established vs control	Early vs control	Established vs early
Kinematics and kinetics							
Knee flexion angle at touch-down, degrees	16.01 ± 3.0	15.66 ± 3.5	16.78 ± 4.0	0.651			
Peak knee flexion angle (PKFA), degrees	31.01 ± 6.1	29.02 ± 4.2	30.59 ± 6.7	0.636			
Knee flexion excursion, degrees	15.00 ± 4.4	13.36 ± 3.8	13.81 ± 4.3	0.568			
Peak knee adduction moment (PKAM), Nm/kg	0.37 ± 0.4	0.29 ± 0.1	0.30 ± 0.3	0.697			
Knee adduction angular impulse moment (KAAI), Nms/kg	0.23 ± 0.3	0.16 ± 0.1	0.17 ± 0.2	0.598			
Peak knee flexion moment, Nm/kg	−0.68 ± 0.4	−0.65 ± 0.1	−0.69 ± 0.3	0.908			
Peak knee external rotation moment, Nm/kg	−0.07 ± 0.1	−0.07 ± 0.1	−0.10 ± 0.1	0.617			
Muscle activity[a]							
Vastus medialis (VM)	0.42 ± 0.1	0.41 ± 0.1	0.43 ± 0.1	0.720			
Vastus lateralis (VL)	0.44 ± 0.1	0.43 ± 0.1	0.43 ± 0.1	0.902			
Medialis hamstrings (MH)	0.29 ± 0.1	0.30 ± 0.1	0.37 ± 0.1	0.025*	0.034*	0.909	0.093
Lateral hamstrings (LH)	0.33 ± 0.1	0.36 ± 0.1	0.39 ± 0.1	0.298			
VMMH co-contraction	0.50 ± 0.2	0.48 ± 0.1	0.64 ± 0.2	0.012*	0.040*	0.976	0.023*
VLLH co-contraction	0.55 ± 0.2	0.64 ± 0.2	0.65 ± 0.2	0.310			
VLMH co-contraction	0.47 ± 0.2	0.51 ± 0.2	0.64 ± 0.2	0.009*	0.012*	0.791	0.064
VMMH/VLLH co-contraction ratio	0.98 ± 0.3	0.89 ± 0.5	1.04 ± 0.4	0.605			

Mean ± standard deviation (SD).
[a] Root mean square from touch-down to PKFA during the stepping-down task.
* p ≤ 0.05 significant difference between groups.

with control subjects ($p = 0.040$) and to patients with early OA ($p = 0.023$) (Table 2) (Figure 4).

3.2. Self-reported knee instability

Seven patients (15%) with knee OA (early $n = 1$; established $n = 6$) reported to have at least one episode of knee instability during the past three months. The incidence of instability was significantly higher in the group with established OA compared with the control ($p = 0.020$). Neither of the patients with self-reported knee instability reported a previous knee injury. None of the characteristics studied such as the biomechanics and EMG activity patterns during the performance of the loading phase of stepping-down task (Table 3) were significantly different between patients with or without self-reported knee instability. However, patients with self-reported knee instability showed significantly lower knee muscle strength compared with subjects without self-reported knee instability (Figure 5).

4. Discussion

This study investigated the biomechanical and neuromuscular strategies during the loading phase of a stepping-down task in a group of patients with early or established knee OA compared to a healthy control group. The main study results showed no difference in the kinematic or

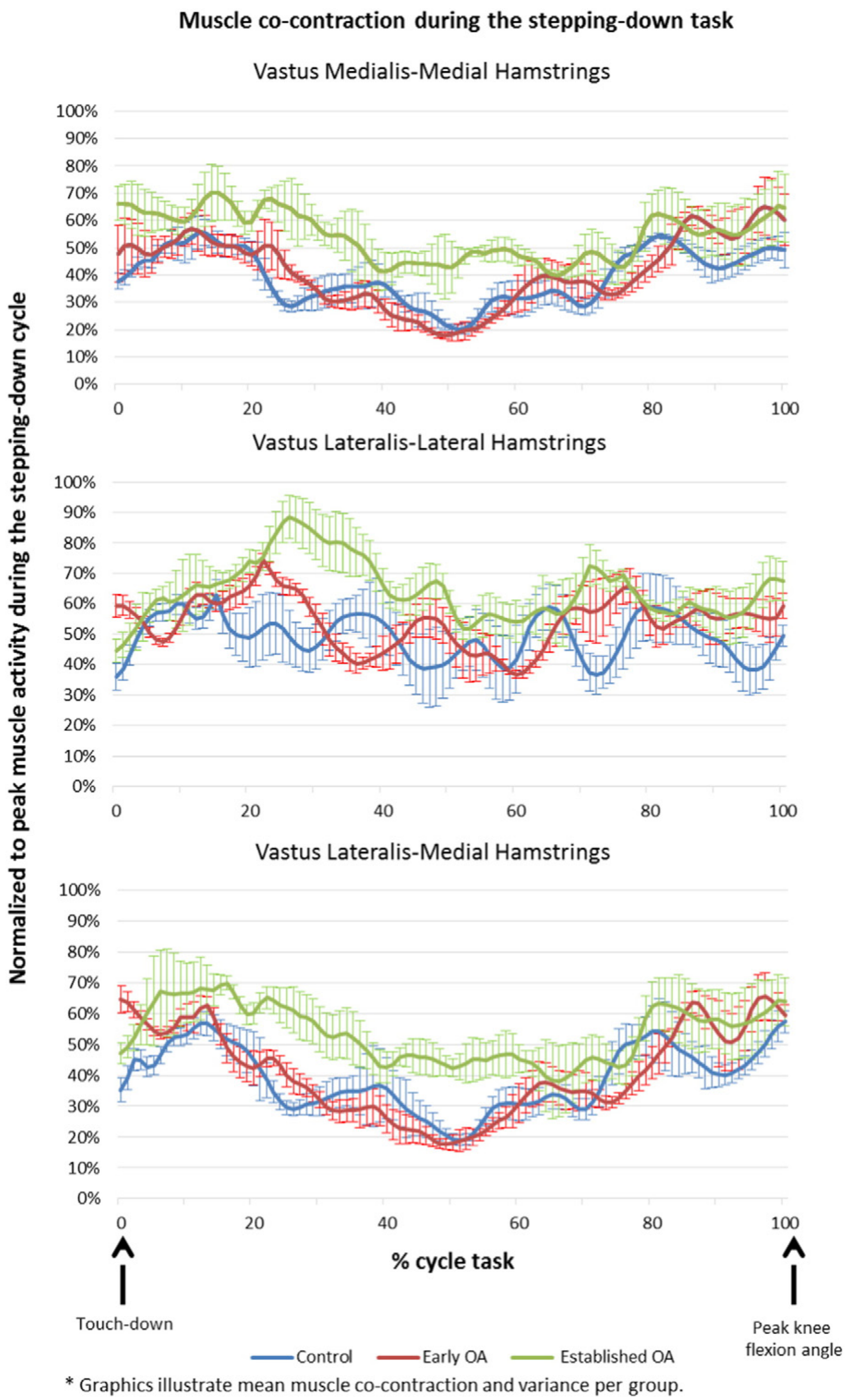

Figure 4. Muscle activity (EMG) of the loading leg was analysed during the stepping-down cycle from the touchdown (0%) to the peak knee flexion angle (100%). Lines represent the mean muscle co-contraction and variance per group.

kinetic characteristics during the loading phase of a stepping-down task between the three groups. However, greater muscle (co-)contraction patterns were observed in patients with established knee OA compared with control subjects and patients with early OA.

There were no significant differences in sagittal plane kinematics or kinetics during the loading phase of the stepping-down task between patients with early or established OA, and control subjects. Based on these results, it is possible to conclude that an isolated stepping-down task might not be challenging enough to identify kinematic and kinetic differences between the three groups studied. Decreased knee flexion angle excursion was previously reported in patients with established knee OA during a step down task from 20 cm [8]. However, in the present study, no significant difference in the knee flexion angle at touch-down, at peak knee flexion during the stance phase or in flexion excursion was found between the three groups studied during the loading phase of the stepping-down task. The difference between both studies could be related to the fact that in the study carried out by Childs et al. [8] the subjects continued to walk forward several steps after stepping-down, which may have allowed a more natural performance of the task. The setting in our laboratory restricted the task only to one step forward after stepping down (Figure 1).

Peak knee adduction moments and knee adduction angular impulse during the loading phase of the stepping-down task were not significantly different between the three groups (early OA, established OA and control subjects). Higher adduction moments during gait have been previously found in patients with established knee OA in the medial compartment [10,11,56], however not in subjects with early OA. It is therefore expected that knee OA severity in the medial-compartment is associated with greater peak adduction moments. However, the discrepancy with the results from the present study might be explained by the more heterogeneous distribution of the structural features in the knee joint which is in line with previous findings from Messier's et al. [57]. In addition, it is possible that the lack of association between OA severity and knee adduction moment found during gait by other authors might not be present during the loading phase of the stepping-down task evaluated in the present study. Assessing the kinematics and kinetics of the supporting leg, in the step descent phase might reveal more differences.

Greater medial hamstrings (MH) activity was exhibited in patients with established knee OA compared with control subjects. Additionally, greater medial muscle co-contraction (VMMH) was found in patient with established OA compared to control subjects and to patients with early knee OA. These are in accordance with previous findings and may reflect an effort to compensate higher medial knee laxity, usually present during gait in patients with established OA [23–25]. Additionally, greater co-contraction of the posterior-medial (MH) and the lateral-anterior (VL) sides of the knee was found in the group of patients with established knee OA compared with the control subjects. According to Rudolph et al. [54] high-level co-contraction of opposing muscle groups could result in higher joint compression. These findings suggest not only a higher medial compression of the medial knee compartment of the knee, but also an overall increase in the compressive load through the knee surface in patients with established OA. Previous evidence have suggested that an increase in muscle co-contraction may lead to an increase of the cumulative load on the knee, which in turn might translate in further knee joint damage and disease progression [8].

Seven patients with knee OA without a known history of knee injury reported to have at least one episode of knee instability during the past three months. However, none of the participants reported to have a feeling of knee instability during the performance of the stepping-down task in our laboratory. In the present study, incidence of instability seems to increase with the severity of the disease. However, to the best of our knowledge there is no published evidence to prove this finding and the sample of patients with knee instability in this study was too small to draw firm conclusion. It is possible that the study of biomechanical characteristics of subjects with self-reported knee instability during the stepping-down task might be useful to objectively identify performance characteristics associated with knee instability, which could contribute to develop appropriate strategies oriented to counteract instability in those patients. Nevertheless, probably due to the small number of patients with self-reported knee instability within this study group, the results of this study did not support our hypothesis. Therefore, studies in a larger sample population with self-reported knee instability during the performance of a more challenging task might be needed to further clarify whether or not biomechanical and neuromuscular performance based characteristics might be associated with the feeling of instability in patients with knee OA.

In patients with established knee OA showing muscle weakness, muscle strength training (both extensor and flexor knee muscles [34]) as well as neuromuscular training leading to a selective EMG activity instead of increased and prolonged co-contraction patterns [58,59] may be recommended to preserve joint integrity (Hodges et al. 2015). The influence of neuromuscular training on knee stability still needs to be elucidated. Further studies are needed to disentangle which of the biomechanical and neuromuscular performance based characteristics are driven by pain, instability, structural changes and/or other factors. Overall, it appears necessary to optimize the rehabilitation strategies directed to decrease an abnormal joint loading during diverse activities of

Table 3
Kinematics, kinetics and muscle activity during the stepping-down task in patients with knee OA ($n = 33$) with or without self-reported knee instability.

	Self-reported knee instability				
	Yes ($n = 7$)	No ($n = 26$)	p-Value	r	p-Value
Kinematics and kinetics					
Knee flexion angle at touch-down, degrees	15.12 ± 5.4	16.62 ± 3.2	0.355	−0.166	0.355
Peak knee flexion angle, degrees	30.09 ± 8.2	29.88 ± 5.1	0.951	0.015	0.934
Knee flexion excursion, degrees	14.97 ± 3.5	13.26 ± 4.2	0.331	0.174	0.331
Peak knee adduction moment (PKAM), Nm/kg	0.28 ± 0.4	0.30 ± 0.2	0.874	−0.029	0.874
Knee adduction angular impulse moment (KAAI), Nms/kg	0.22 ± 0.1	0.15 ± 0.2	0.249	0.206	0.249
Peak knee flexion moment, Nm/kg	−0.73 ± 0.4	−0.65 ± 0.2	0.659	−0.125	0.490
Peak knee external rotation moment, Nm/kg	−0.11 ± 0.2	−0.08 ± 0.1	0.705	−0.102	0.572
Muscle activity[a]					
Vastus medialis (VM)	0.43 ± 0.1	0.41 ± 0.1	0.566	0.104	0.566
Vastus lateralis (VL)	0.43 ± 0.1	0.43 ± 0.1	0.948	0.012	0.948
Medialis hamstrings (MH)	0.36 ± 0.1	0.34 ± 0.1	0.507	0.120	0.507
Lateral hamstrings (LH)	0.38 ± 0.1	0.38 ± 0.1	0.857	0.033	0.857
VMMH co-contraction	0.60 ± 0.2	0.57 ± 0.2	0.683	0.074	0.683
VLLH co-contraction	0.63 ± 0.2	0.65 ± 0.2	0.841	−0.036	0.841
VLMH co-contraction	0.60 ± 0.2	0.58 ± 0.2	0.834	0.038	0.834
VMMH/VLLH co-contraction ratio	1.04 ± 0.5	0.96 ± 0.4	0.684	0.073	0.684

Data are presented as mean ± standard deviation and r = Pearson correlation coefficient. No statistically significant differences between groups.

[a] Root mean square from touch-down to PKFA during the stepping-down task.

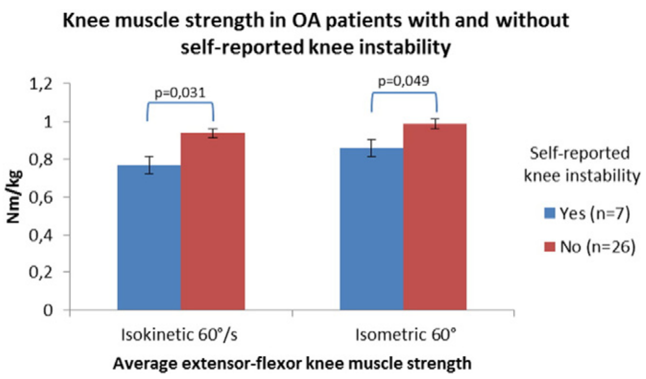

Figure 5. Distribution of knee muscle strength by self-reported knee instability.

daily living in patients with OA. This might potentially contribute to slow down the joint damage and subsequent increase in activity limitations in this group of patients.

Several limitations of the present study should be considered. First, patients with uni- and bilateral knee OA were included in the study. It is possible that patients with bilateral knee OA might have developed different compensatory mechanisms to ambulate compared with patients who have only one knee affected. However, it is very likely that all patients might have had the contralateral knee (undiagnosed) affected to some extent. Overall, there is commonly well-accepted to use an index knee, which includes the more affected knee in patients with bilateral knee OA, for the analyses. Second, pain intensity during the performance of the stepping-down task was not assessed. Authors are aware that pain could have influenced the performance of the stepping-down task. Therefore, in a future study, gathering this information will be considered in order to adjust the analyses.

Third, only a small number of patients with knee OA reported a sensation of knee instability during the past three months. The small number of patients with this characteristic translated into a lack of statistical power which did not allow us to draw strong conclusions about the biomechanical characteristics in patients with self-reported knee instability from these analyses. Fourth, it was not possible to perform further analyses by frequency of knee instability also due to the small number of patients with self-reported knee instability. It is possible that patients with a higher number of episodes of knee instability may have different biomechanical characteristics than patients with a lower number of episodes. Therefore, self-reported knee instability should be used as an inclusion criterion on for further studies in order to evaluate the kinetic and kinematic characteristics associated with the sensation of knee instability. Fifth, differences in patients' height might have had a potential influence on descending from a step [54]. However, there were no statistical differences in height between the three study groups (Table 1). Additionally, a 20 cm step is considered a standard step height mimicking daily live scenarios involving stairs regardless of the height of the patients. Lastly, assessing a flight of stairs rather than one step-down might have revealed more differences.

5. Conclusions

The greater EMG activity found during the loading phase of the stepping-down task in established OA might suggest a less efficient use of knee muscles or an attempt to increase knee stability. Statistically significant differences in the other analysed variables were not found.

Conflict of interest

The authors of this article declare that they have no conflict of interest.

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